Performance and Safety Studies on COTS Li-ion Cells of Cylindrical and Pouch c Cell Designs

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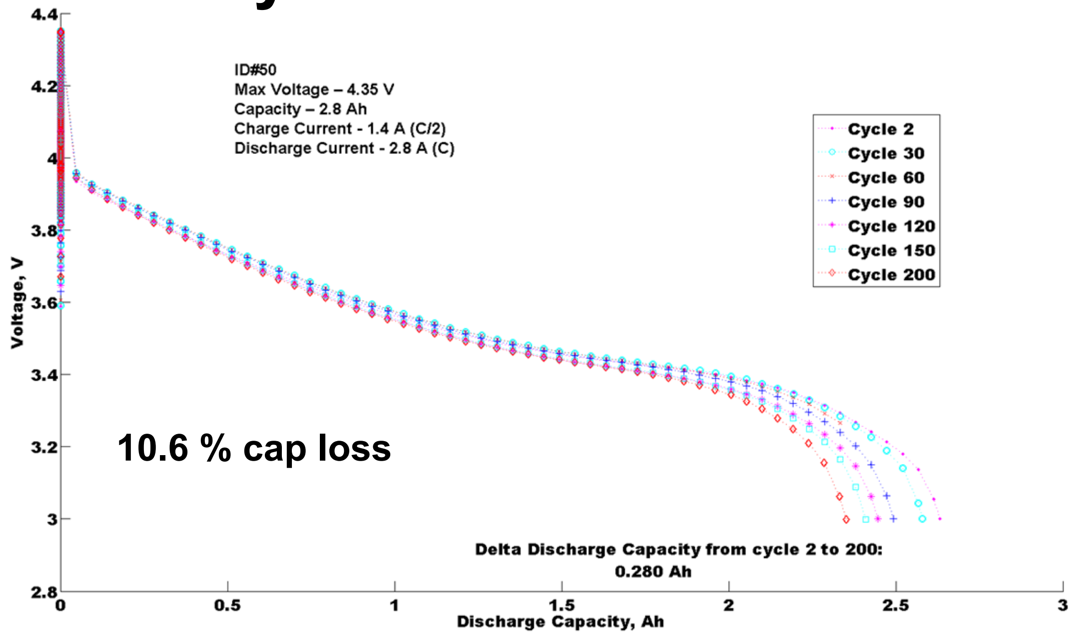
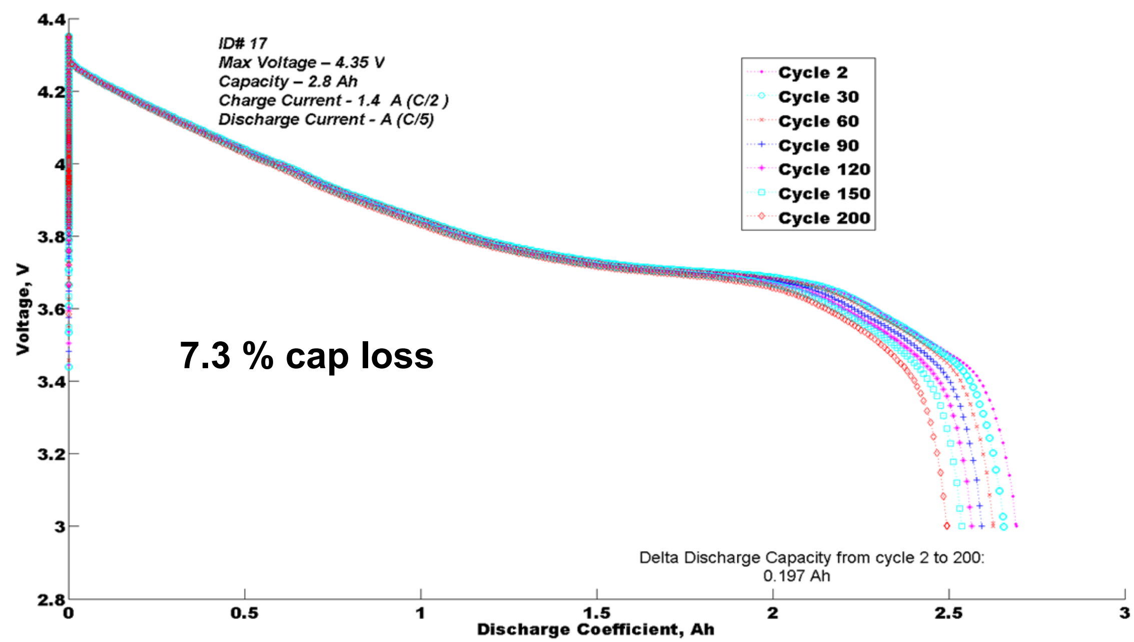
Introduction

- NASA-JSC's state-of-the-art cell surveillance program allows the battery group to test cells available in the commercial market as well as custom designed cells.
- Cell designs of the cylindrical and prismatic pouch from a few different cell manufacturers were studied in FY11.
  - LG 2.8 Ah 18650 Li-ion
  - Tenergy 6.0 Ah li-ion pouch
  - Li-ion 5.5 Ah pouch (cycle life testing only)
- Other test programs: D size high energy cell; micro-strain gage studies with different cell designs; Li-S cell test
- Typical tests carried out include performance and abuse as indicated for each cell test program in the next few charts.

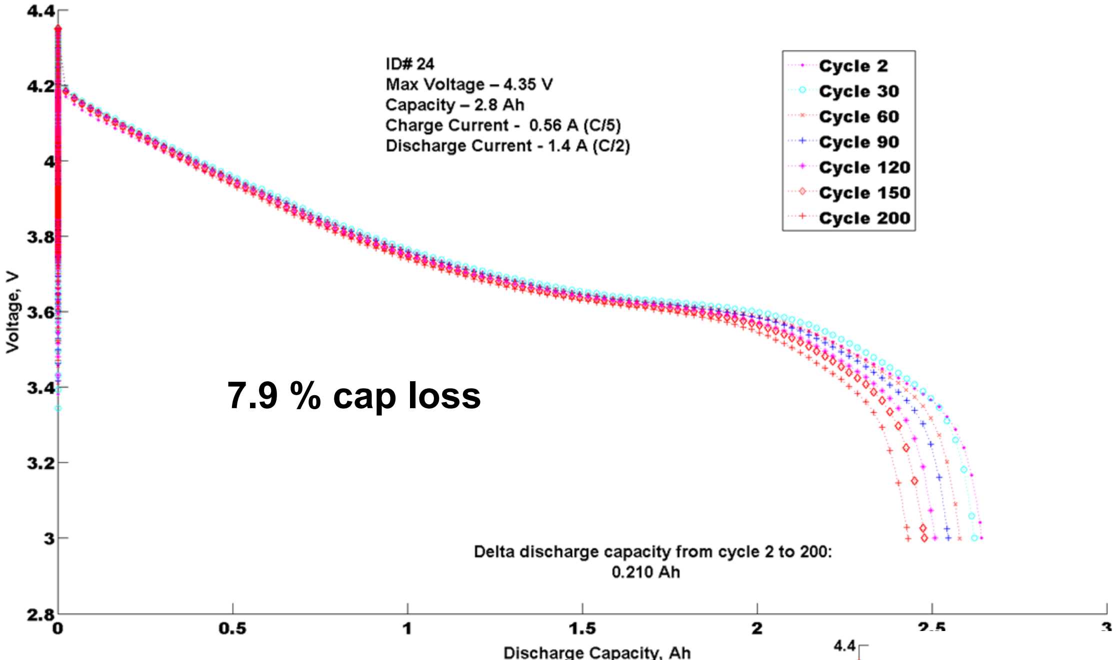
Cycle Life Test on LG 18650 Li-ion 2.8 Ah Cell

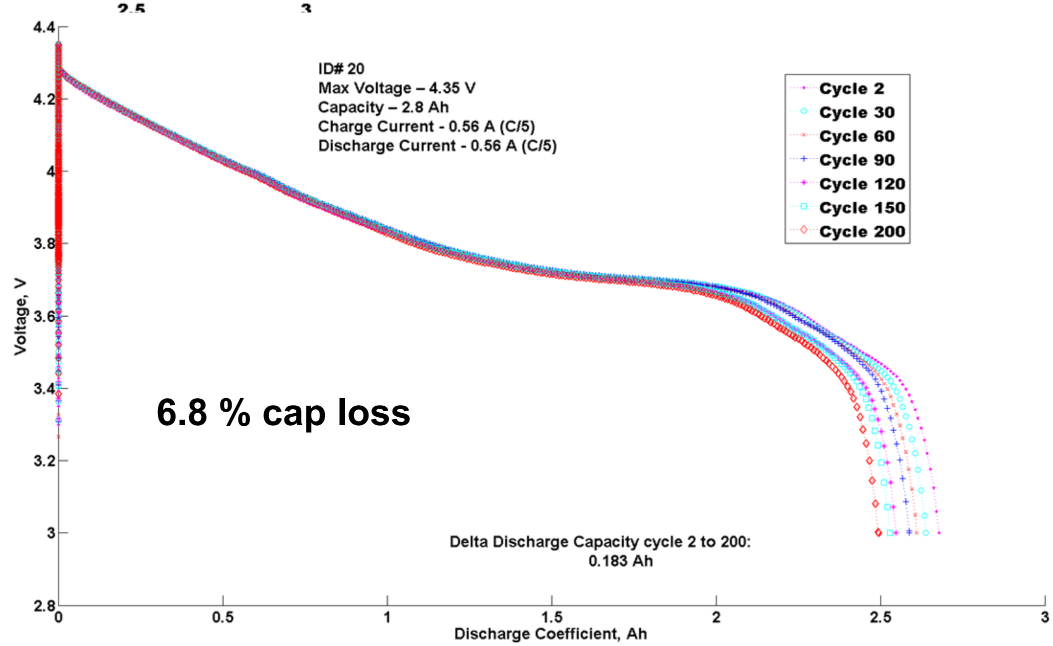


214 Wh/kg

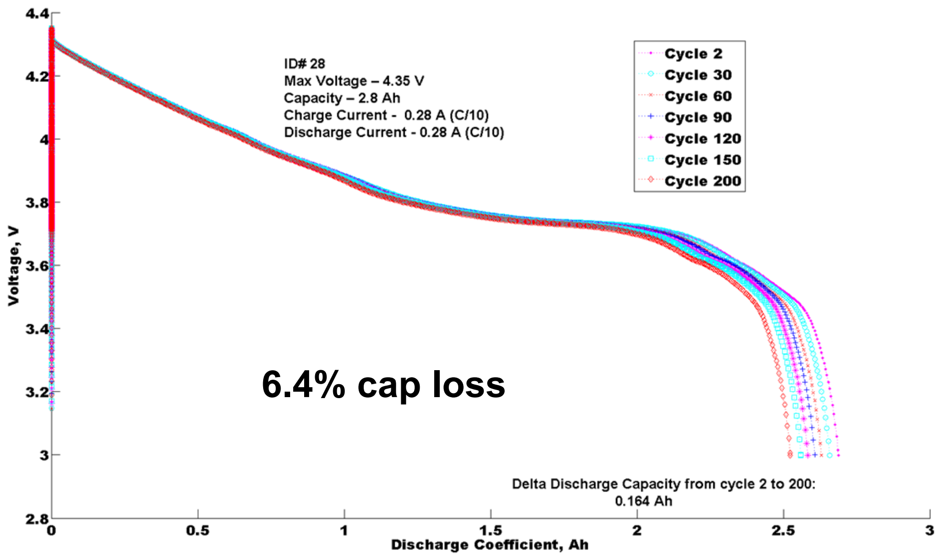


Cvcle Life Test for LG 18650 2.8 Ah cell





Cycle Life Test for LG 18650 Li-ion 2.8 Ah Cell



Tenergy 6.0 Ah Prismatic Pouch Li-ion cell

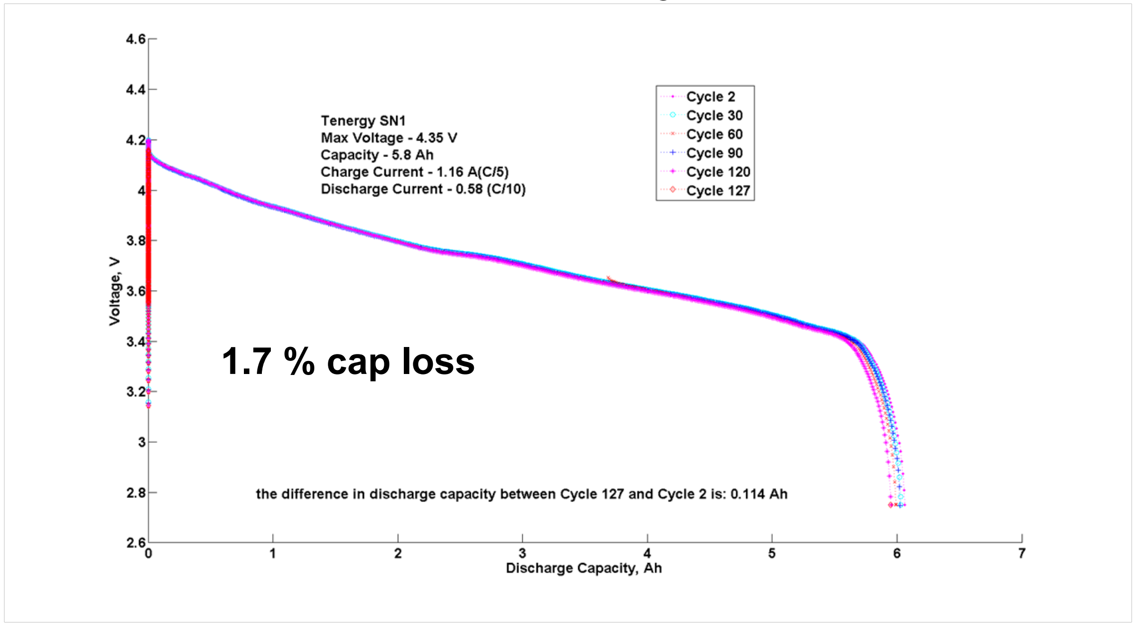
Tenergy Cells underwent performance as well as safety tests.

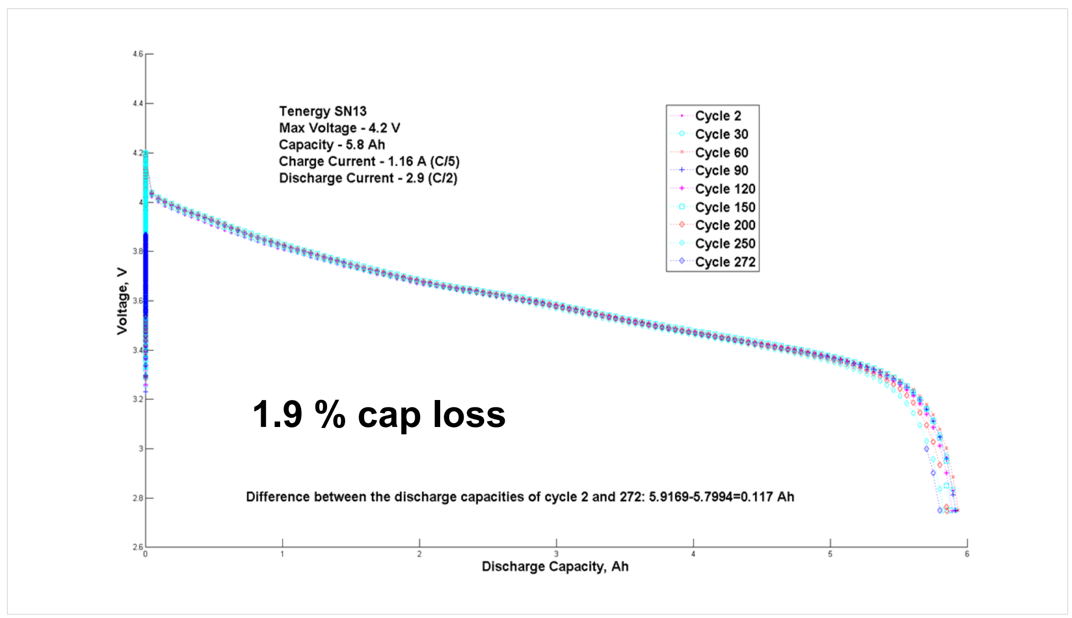
- Table 1 below gives a list of the protocols that were used to determine the cell's rate capability.
- Cycle life testing is currently still under progress.

Table 1. Protocols used for Rate Capability Tests

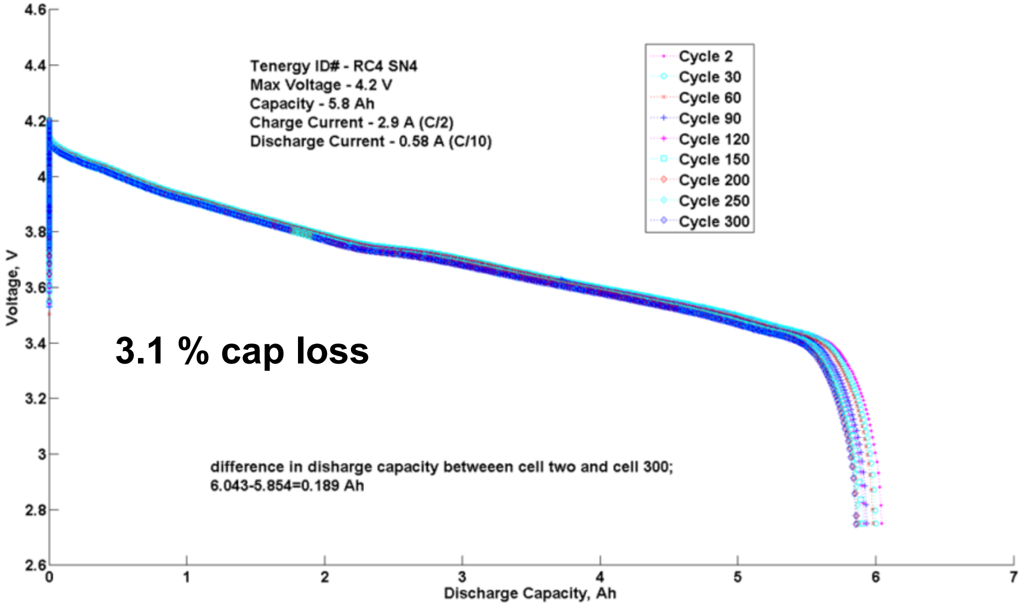
Protocol No.	Charge Rate (A)	Discharge Rate (A)	Number of Cycles
1	2.90 c/2	5.80 c/1	300
2	2.90 c/2	2.90 c/2	300
3	2.90 c/2	1.16 c/5	300
4	2.90 c/2	0.58 c/10	300
5	1.16 c/5	5.80 c/1	300
6	1.16 c/5	2.90 c/2	300
7	1.16 c/5	1.16 c/5	300
8	1.16 c/5	0.58 c/10	300

Rate Capability Tests for Tenergy Li-ion Cell

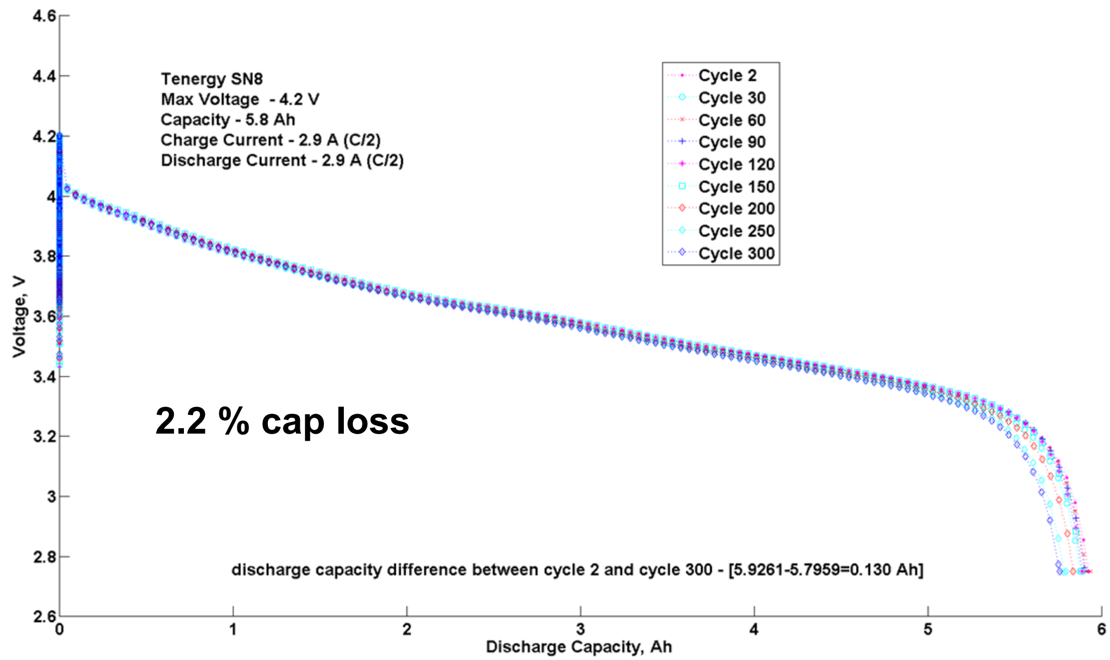




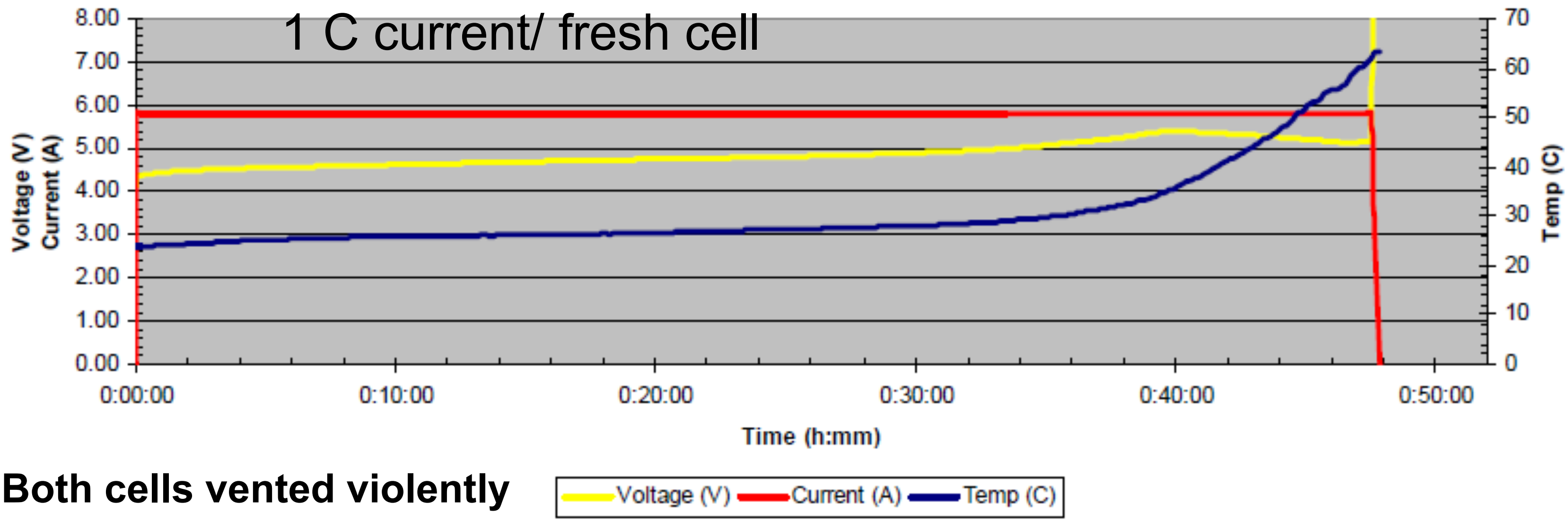
Rate Capability Tests for Tenergy Li-ion Cells



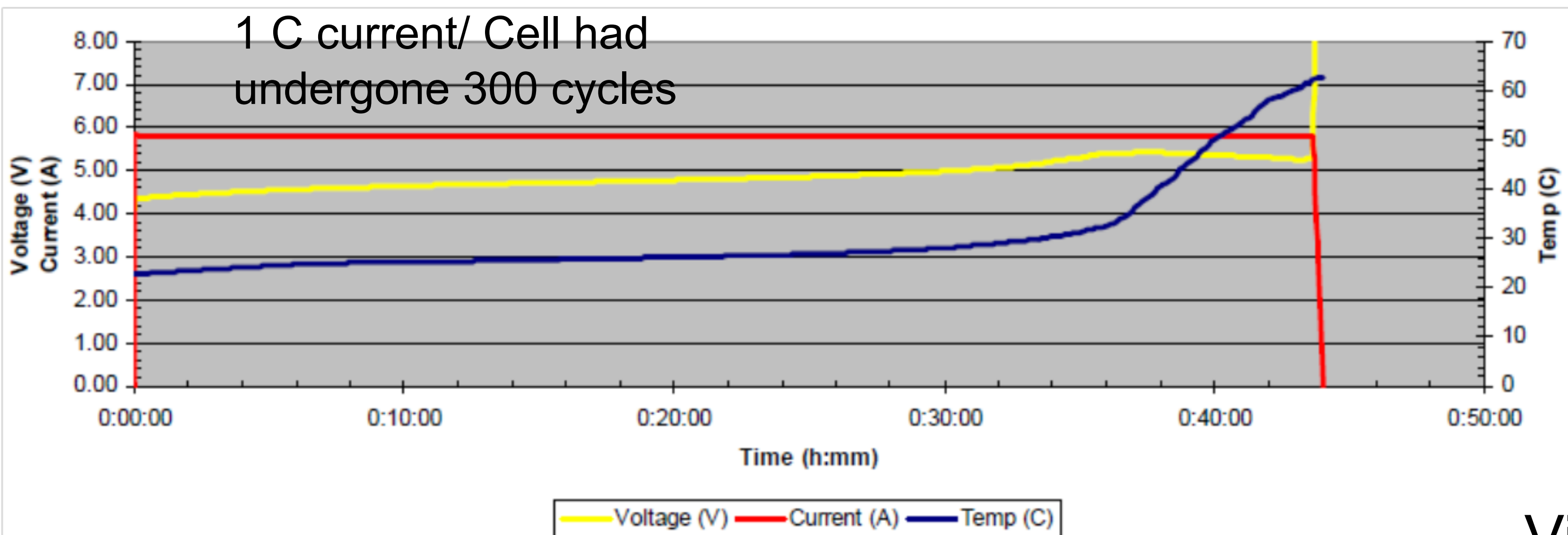
2% less initial cap between C/10 and C/2



Tenergy 6.0 Ah Li-ion Prismatic Pouch Cell Overcharge Test



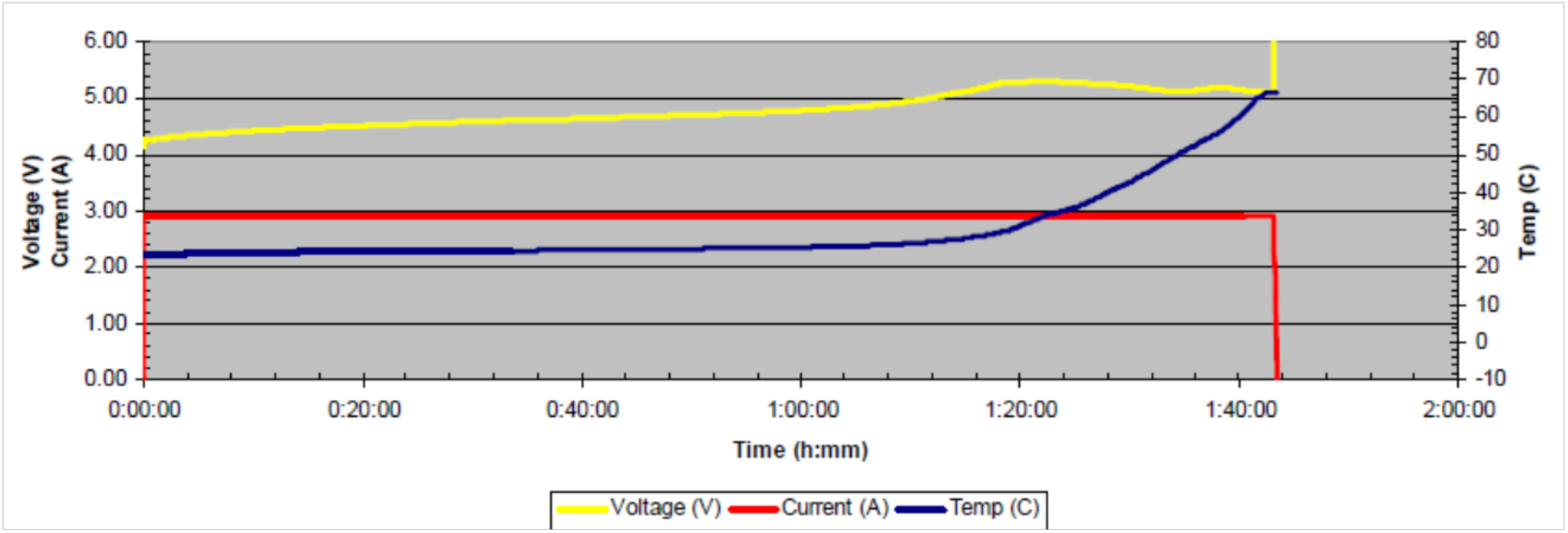
Both cells vented violently



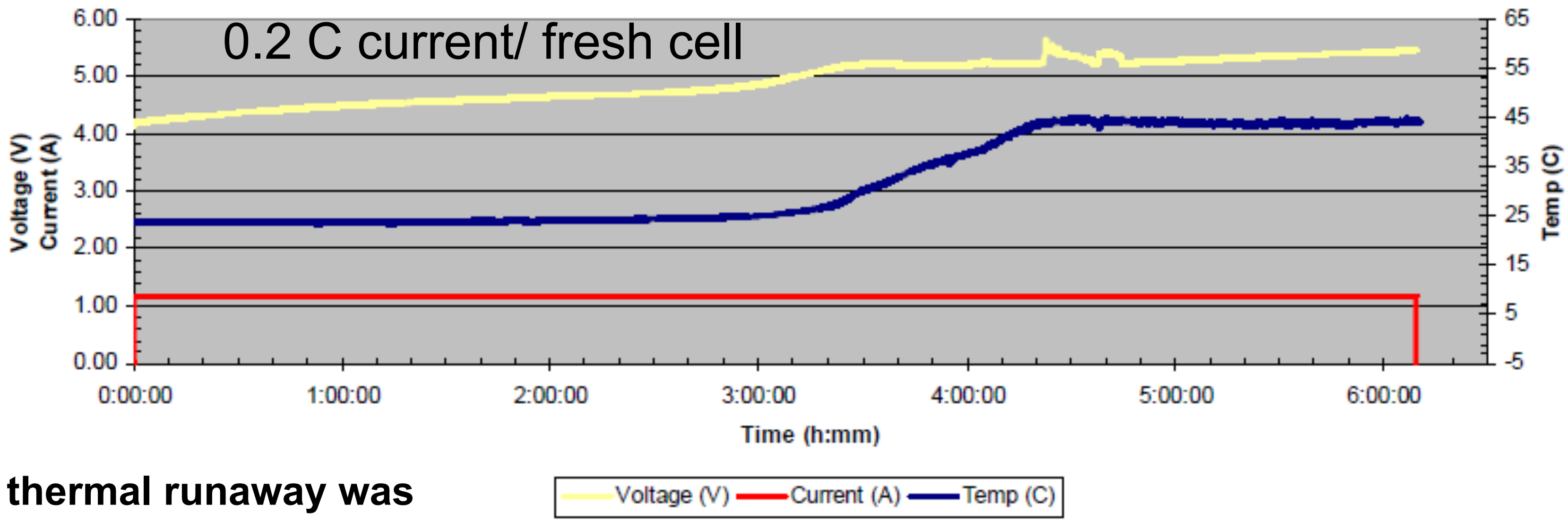
Video

Overcharge Test on Tenergy 6.0 Ah Li-ion Prismatic Pouch Cell

0.5 C current/ fresh cell

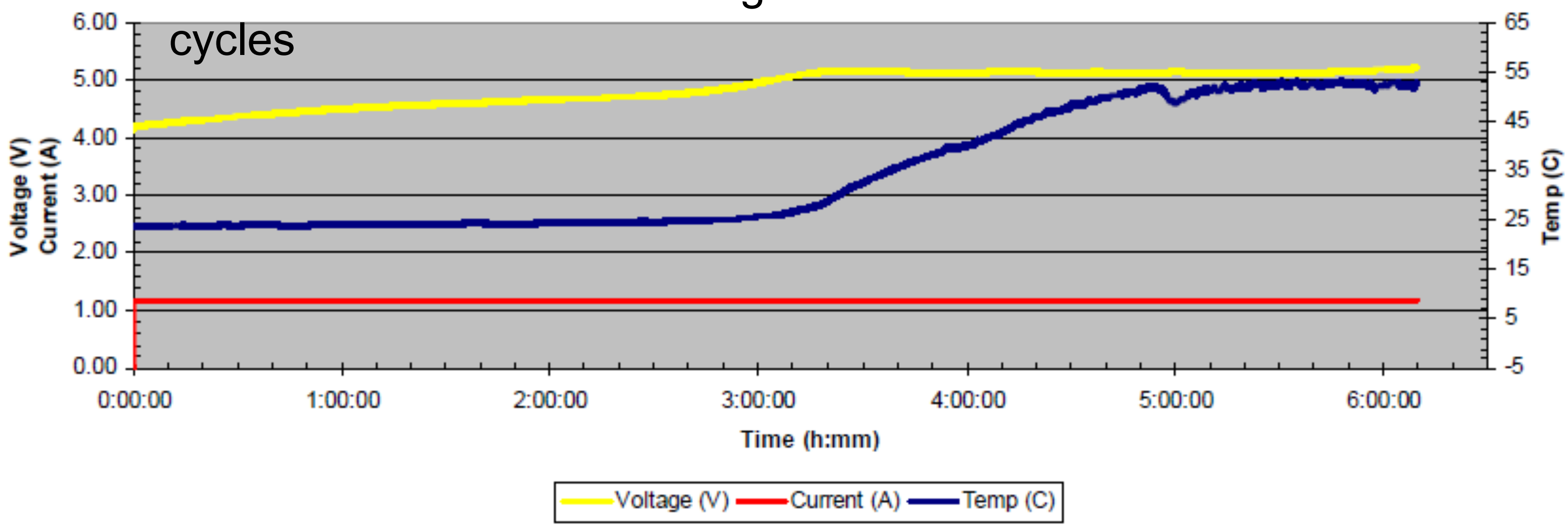


Overcharge Test of Tenergy 6.0 Ah Li-ion Cell

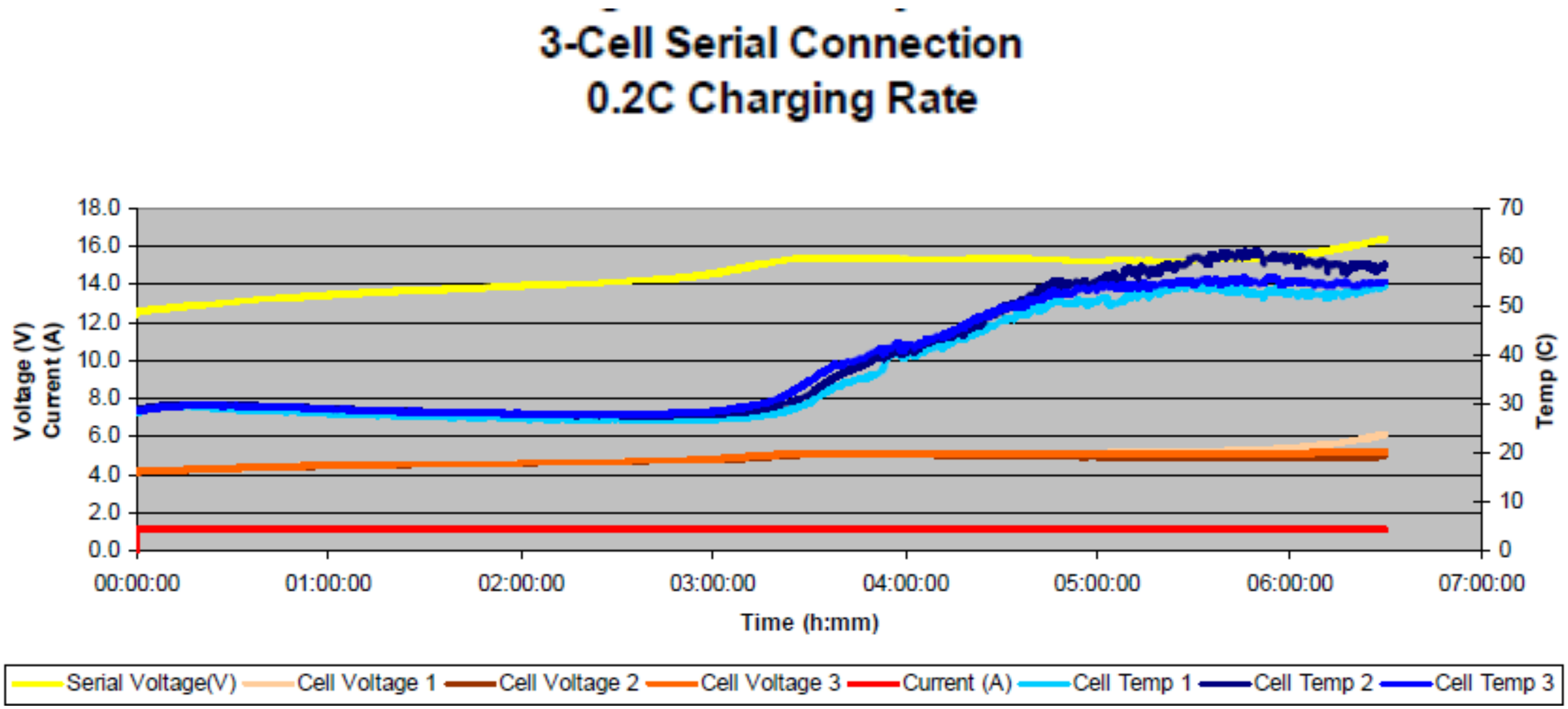


No thermal runaway was Observed in both cases

0.2C current/ Cell had undergone 300 cycles



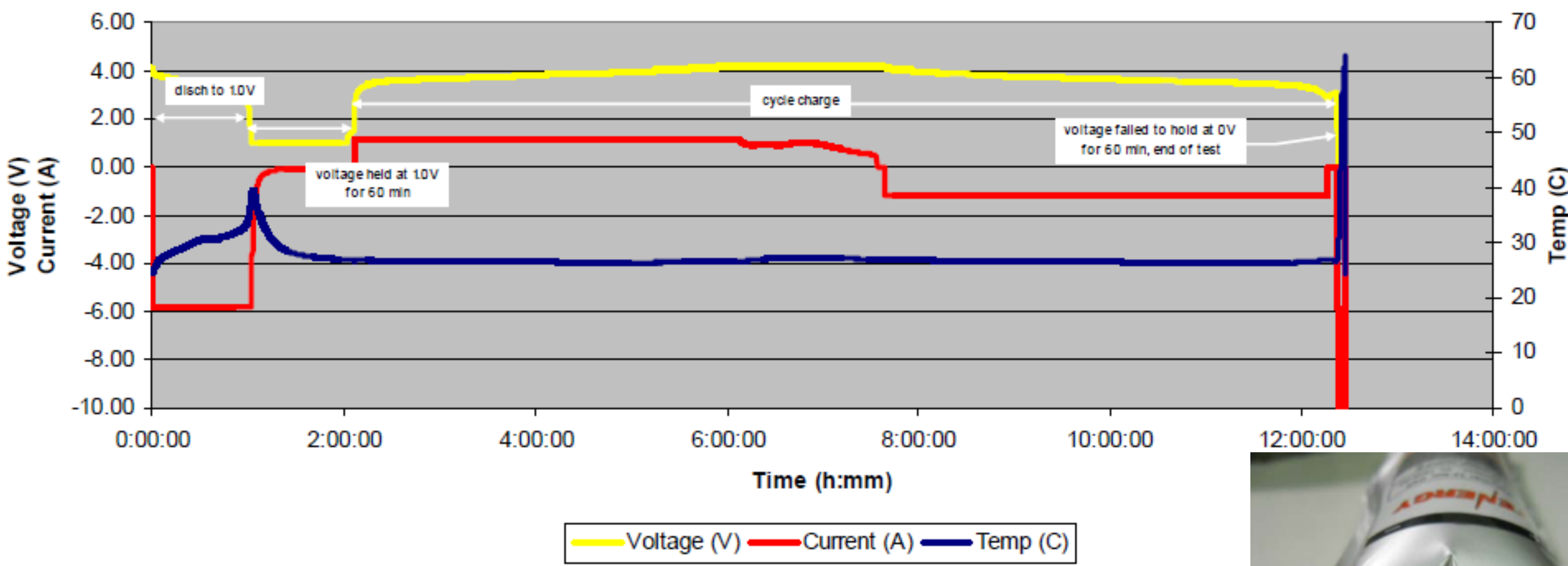
Overcharge Test of Tenergy 6.0 Ah Li-ion Cell



No thermal runaway

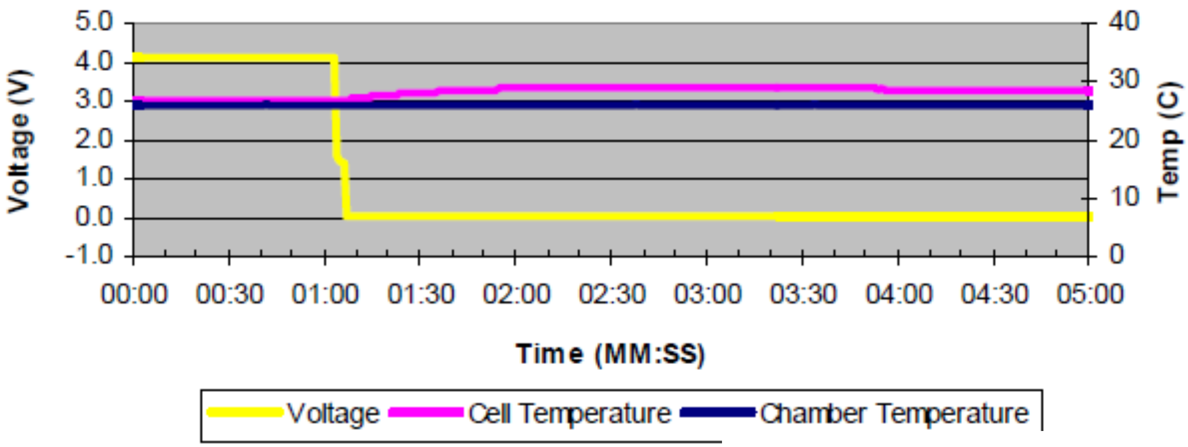
Overdischarge Test on 10S Unbalanced Cell Module

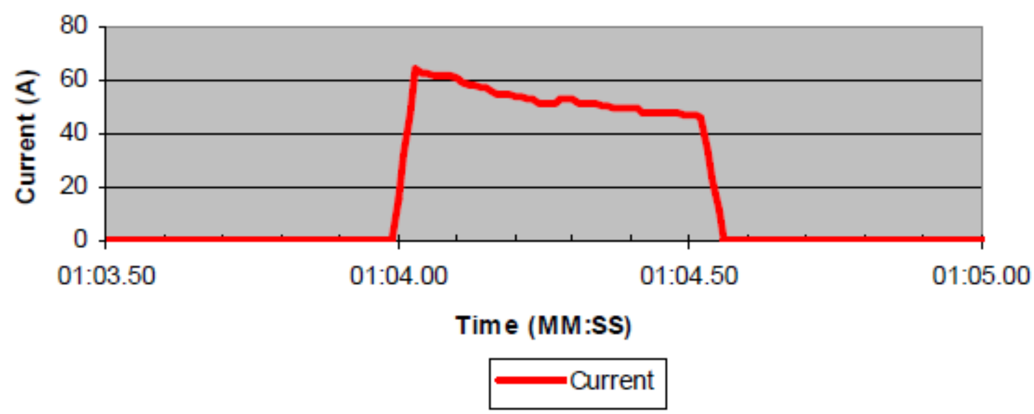
Test Temp ('C)	Sample Condition	Sample #	Sample ID	Charge Current (mA)	Voltage Condition (V)	Initial OCV (V)	Initial ACR (mOhm)	Maximum Temp ('C)	Notes
20	Fresh Chg	1	12	5.8	0-1	4.1372	20.4	64.0	Minor Venting, Bloated Cell
20	Fresh Chg	2	13	5.8	0-1	4.1378	20.2	85.9	Minor Venting, Bloated Cell
20	Fresh Chg	3	16	5.8	0-1	4.1310	20.1	75.9	Minor Venting, Bloated Cell



External Short Test on Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

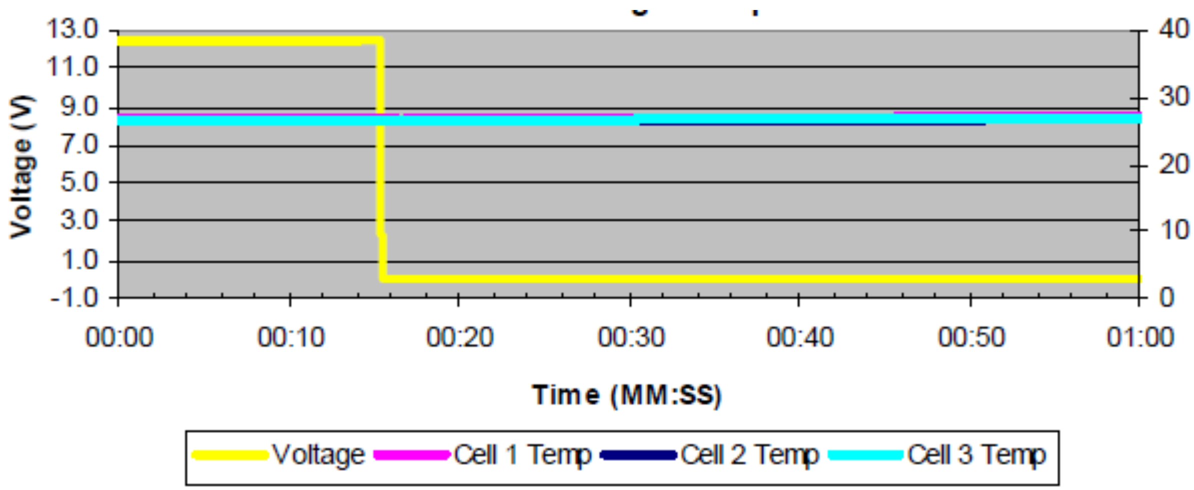
Test Temp (°C)	Sample Condition	Sample #	Sample ID	Resistance (mOhm)	Initial OCV (V)	Initial ACR (mOhm)	Maximum Temp (°C)	Maximum Current (A)	Notes
20	Fresh Chg	1	11	30	4.1284	20.4	28.9	62.0	Cathode tab burned off
20	Fresh Chg	2	8	30	4.1327	20.4	27.2	63.0	Cathode tab burned off
20	Fresh Chg	3	9	30	4.1325	20.3	29.7	65.0	Cathode tab burned off
20	Fresh Chg	3-Cell	25,26,27	27	12.431	63.2	27.2	113.0	Cathode tab burned off

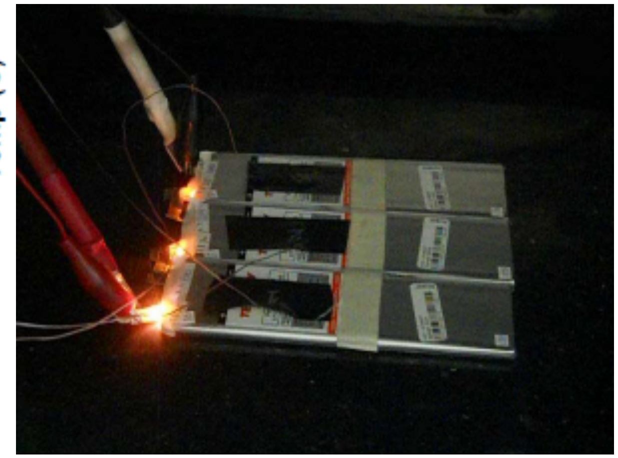


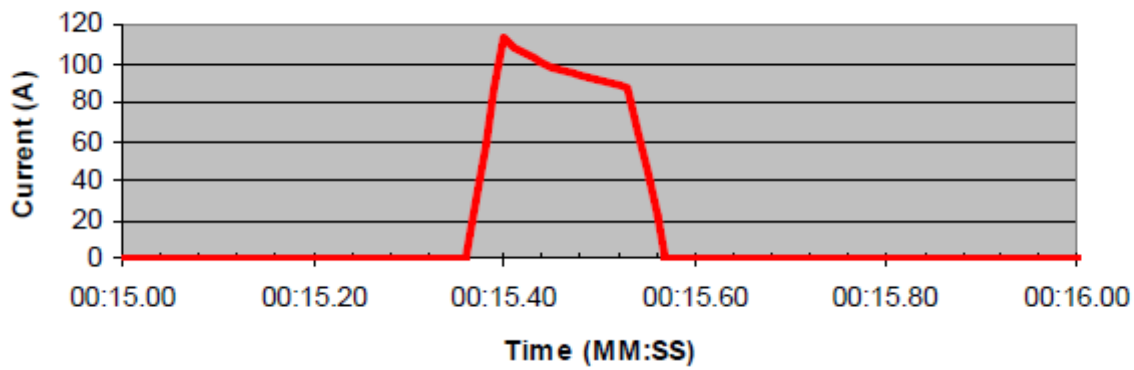


External Short Test on 3S String of Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

113 A max; 27 deg C max





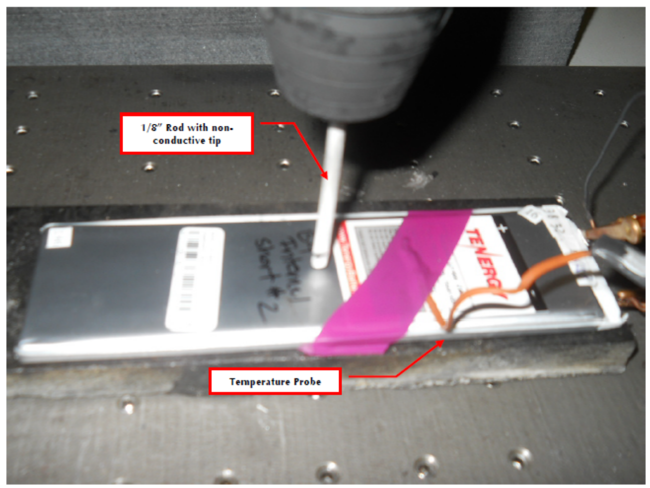


Cathode Tabs from all three cells burned off and became disconnected

Simulated Internal Short Test on Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp ('C)	Sample Condition	Sample #	Sample ID	Initial OCV (V)	Initial ACR (mOhm)	Maximum Temp ('C)	Notes
20	Fresh Chg	1	18	4.140	20.5	172.6	Fire
20	Fresh Chg	2	20	4.137	20.6	309.8	Fire

Table 2.4.1: Test Summary Table



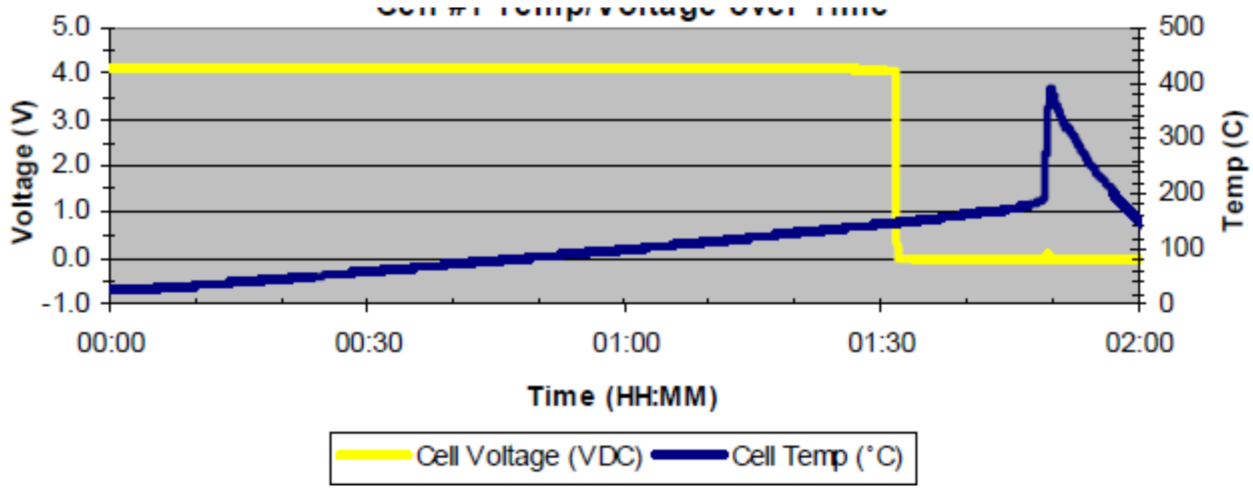
Burst Pressure Test for Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp ('C)	Sample Condition	Sample #	Sample ID	Max Pressure (kPa)
20	Fresh Chg	1	40	662
20	Fresh Chg	2	5	617

89/96 psi

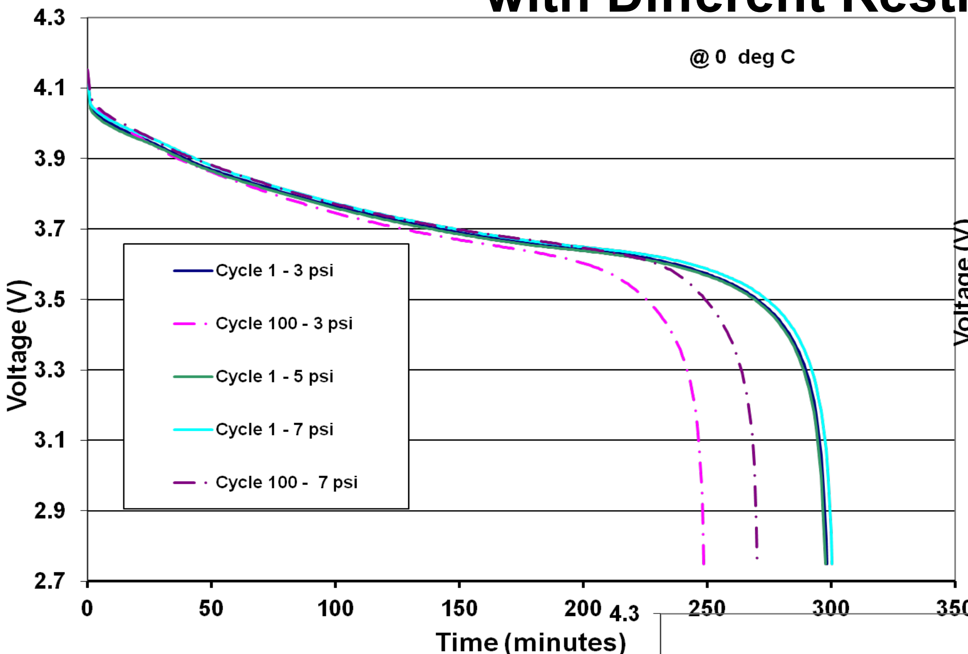
Heat-to-Vent Test for Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

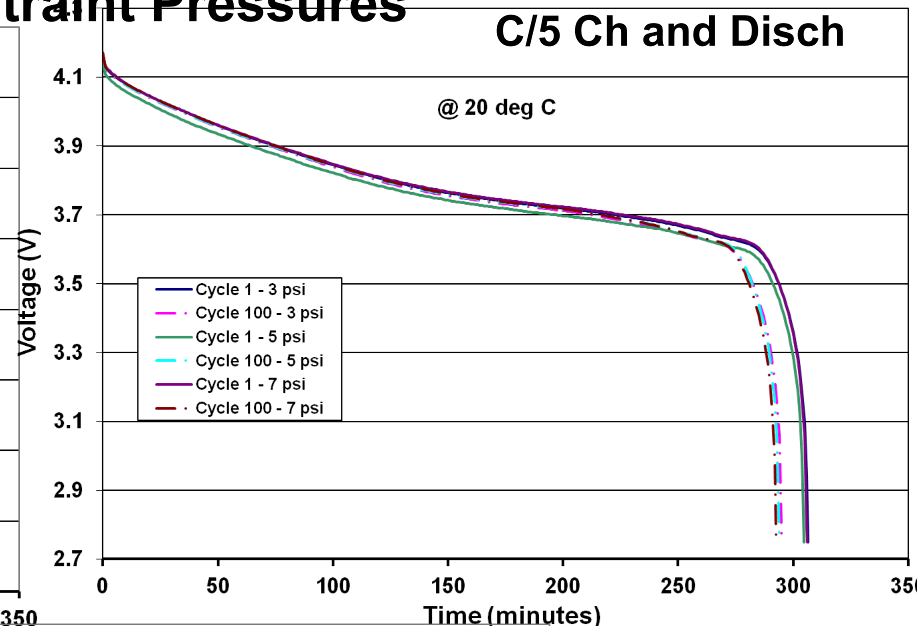
Test Temp ('C)	Sample Condition	Sample #	Sample ID	Initial OCV (V)	Initial ACR (mOhm)	Maximum Temp ('C)	Notes
20	Fresh	1	15	4.1438	20.3	189.8	Fire
20	Fresh	2	14	4.1397	20.5	192.0	Fire

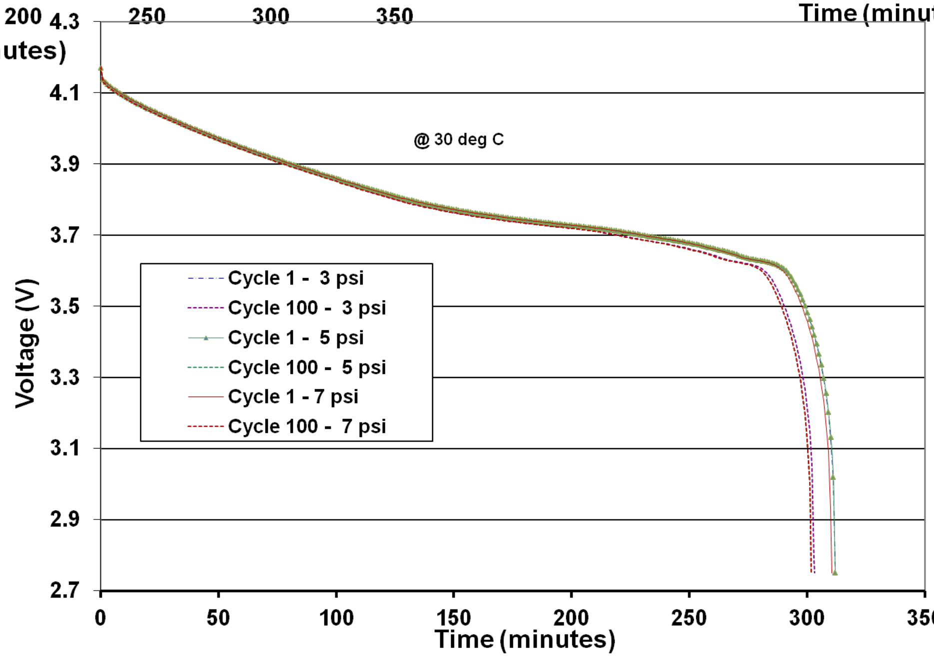


Li-ion 5.5 Ah Pouch Cell Cycle Life Test with Different Restraint Pressures

C/5 Ch and Disch

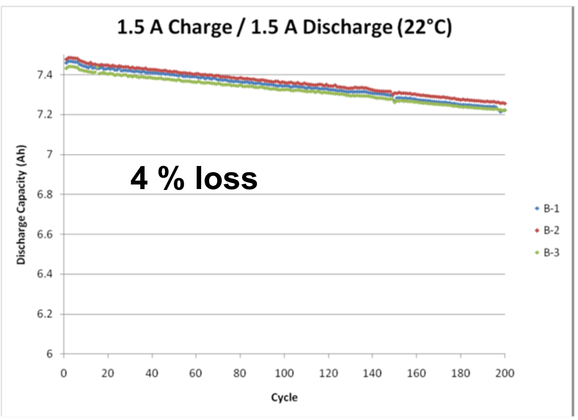


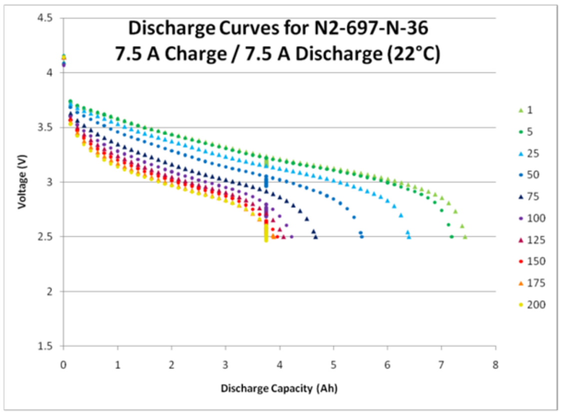




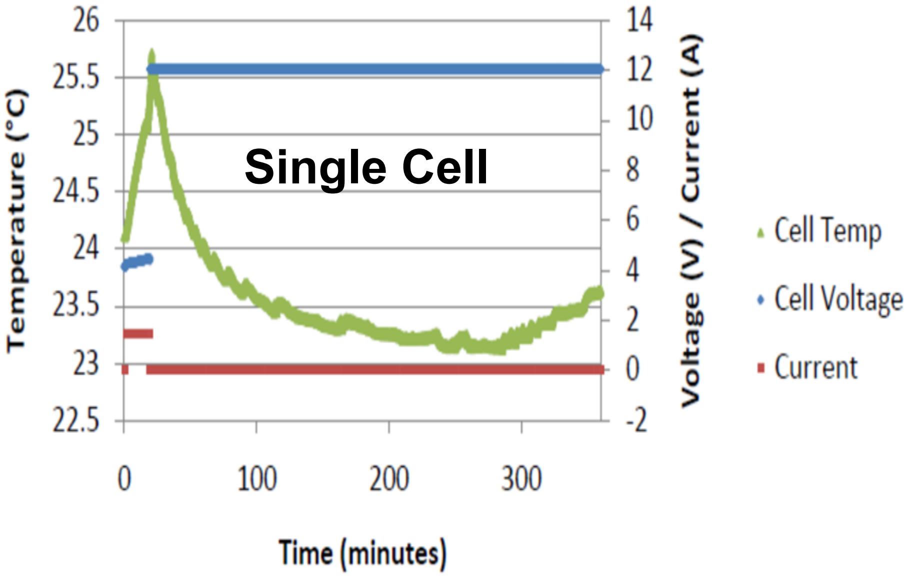
High Energy D Cell Test Program

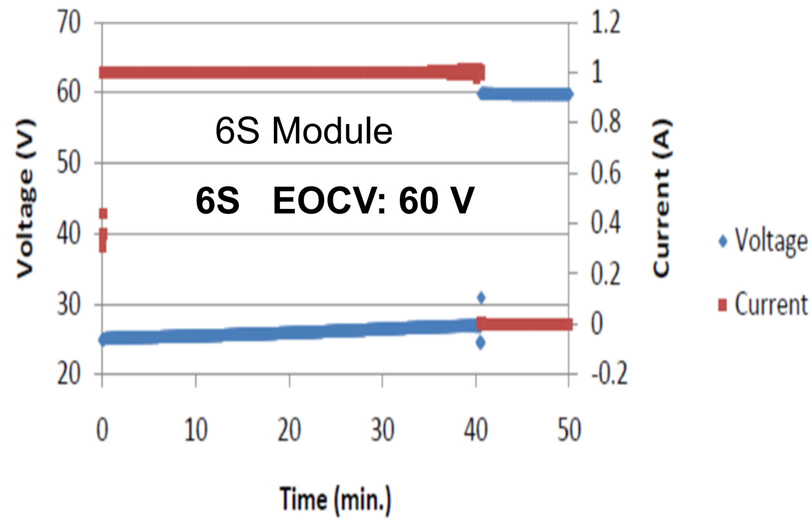
- 7.5 Ah D cell
  - Has unique cell design with a circuit board inside the cell in the header area
  - Protects against overvoltage and overcurrent, with no resets – cell fails in a fail-safe mode
  - Observed cell inconsistencies and the cell could not perform at the low temperatures specified in the cell specification; medium 1 C rate cycling showed large drop in capacity at 200 cycles.
- 186 Wh/kg C/2 rate/ RT
- At 0 ^{0}C, 10 % loss in capacity compared to RT; 69% loss in capacity over 100 cycles



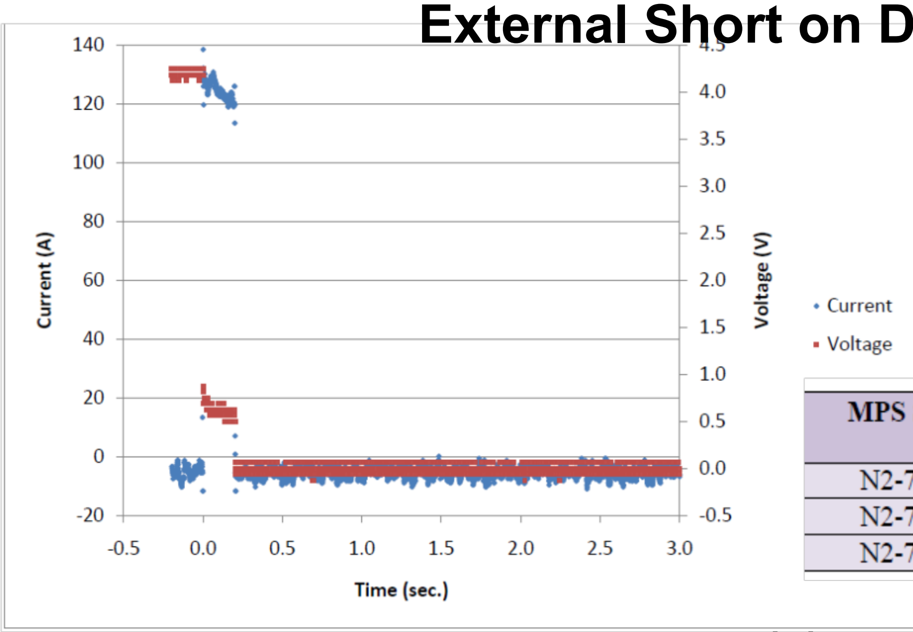


D-Cell Single Cell and 6S Module Overcharge at C/5 Rate and C/2 respectively





External Short on D-Cell



MPS Sample ID	Initial short-circuit current (A)	Time for cell to go open (sec.)	Initial Temp. (°C)
N2-748-SC-19	130	0.267	24.6
N2-748-SC-20	130	0.344	23.9
N2-748-SC-21	130	0.201	23.3

Li-S Pouch Cells

ID211: Cycle 1 – 4.59Ah **33 % loss**
Cycle 92 – 3.08Ah
(charge rate of 450mA and discharge rates of 450mA)

ID20D: Cycle 1 – 4.56Ah **28.5 % loss**
Cycle 92 – 3.26Ah
(charge rate of 450mA and discharge rates of 450mA)

18 deg C Chamber Temp for all cycling

ID216: Cycle 1 – 4.56Ah
Cycle 79 – 3.26Ah
Cycle 100 – 1.76Ah
(charge rate of 450mA and discharge rates of 450mA)

At 79 cycles, 28.5% loss
At 100 cycles, 61 % loss

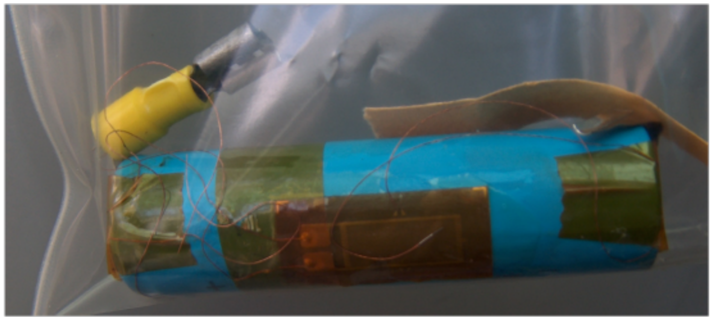
ID20F: Cycle 1 – 4.50Ah **29 % loss**
Cycle 92 – 3.19Ah
(charge rate of 450mA and discharge rates of 700mA)

BOL: 393 Wh/kg
(JSC) EOL: 256 Wh/kg

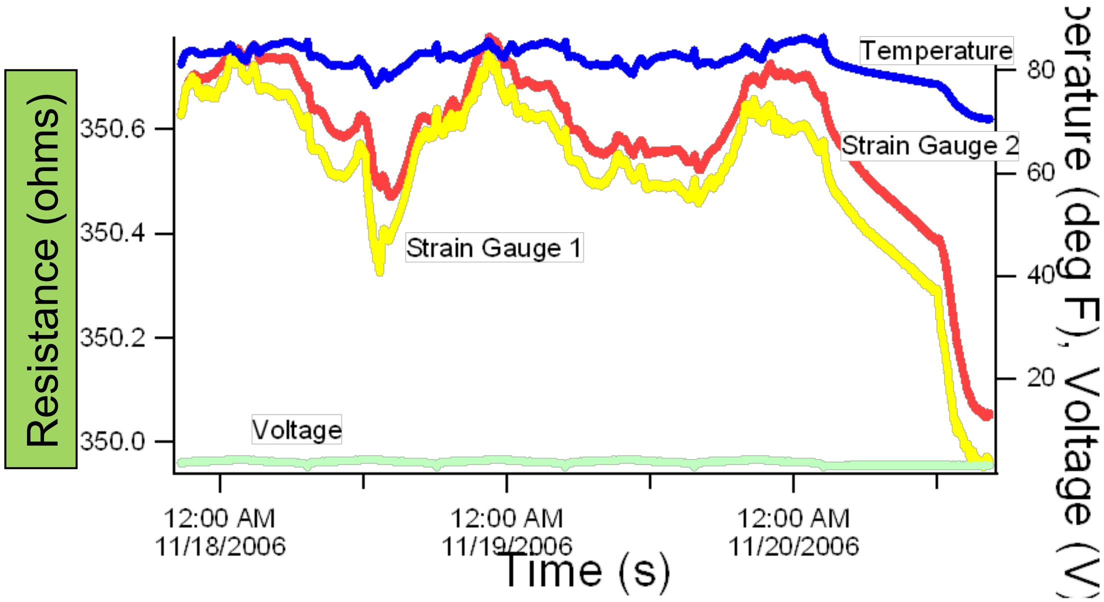
Use of MicroStrain Gages as a Safety Control for Lithium-ion Batteries

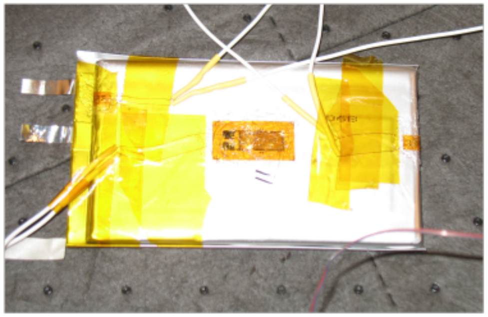
Presented at 5th IAASS Conference

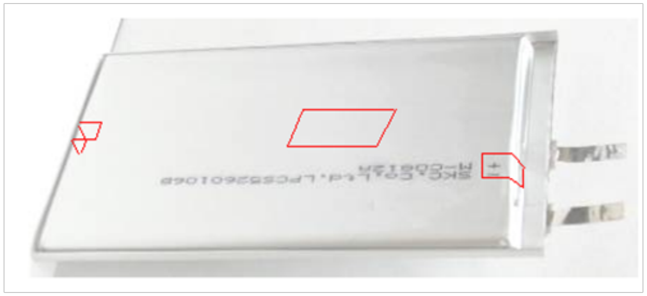
- Strain gage used during testing of different cell designs under various Normal and abuse conditions.
  - **Normal charge and discharge cycling at various rates**
  - **Overcharge**
  - **Overdischarge into reversal**
  - **External short circuit**
  - **Simulated Internal short (crush)**
  - **Heat-to-vent**
  - **Each one of these tests had various parameters too such as the rates of abuse (C/2 charge vs C/5 charge and so on)**
- Cell Designs tested:
  - **18650, 26650 Cylindrical (metal can)**
  - **Plasticized Pouch polymer**
  - **Prismatic –metal can**
- Other Parameters Tested:
  - **Strain gages placed on tabs at the terminal ends**

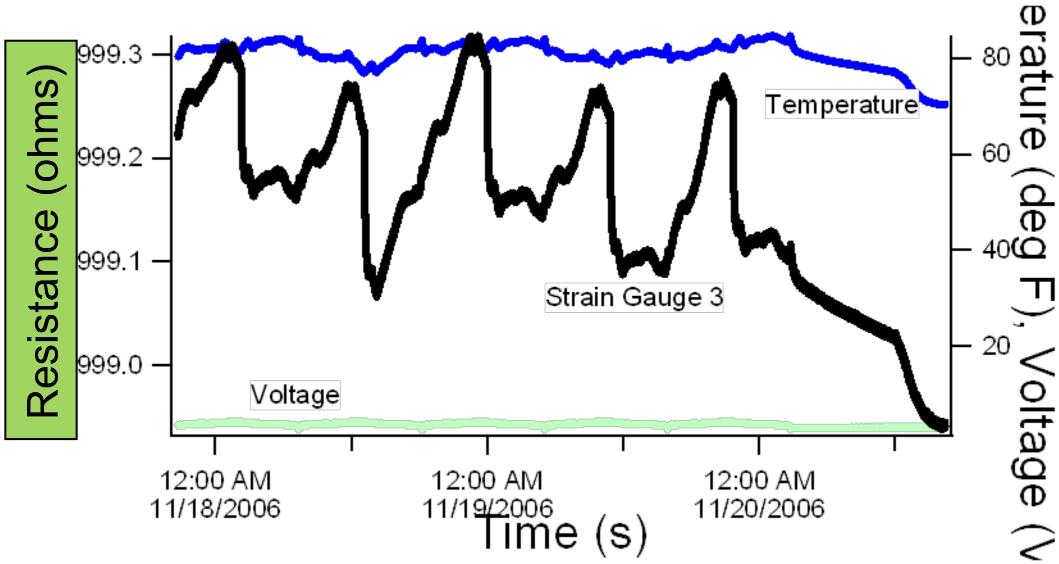


Normal Charge/Discharge of Polymer Pouch Lithium-ion Cell

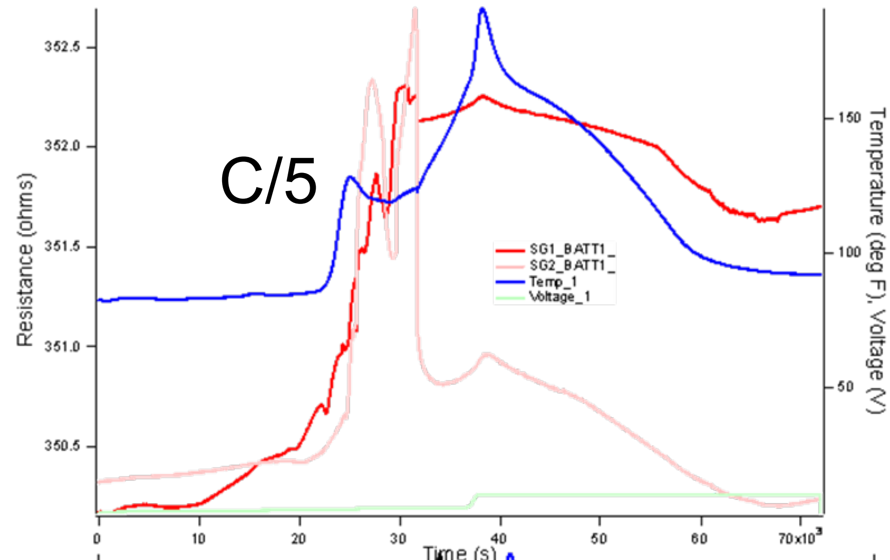


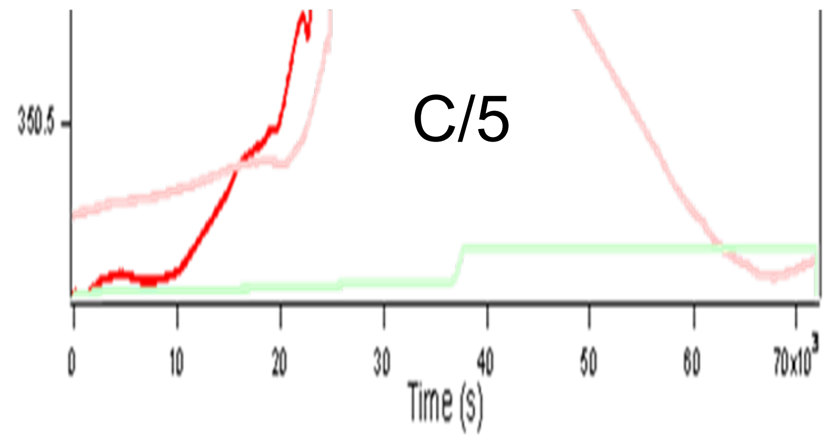


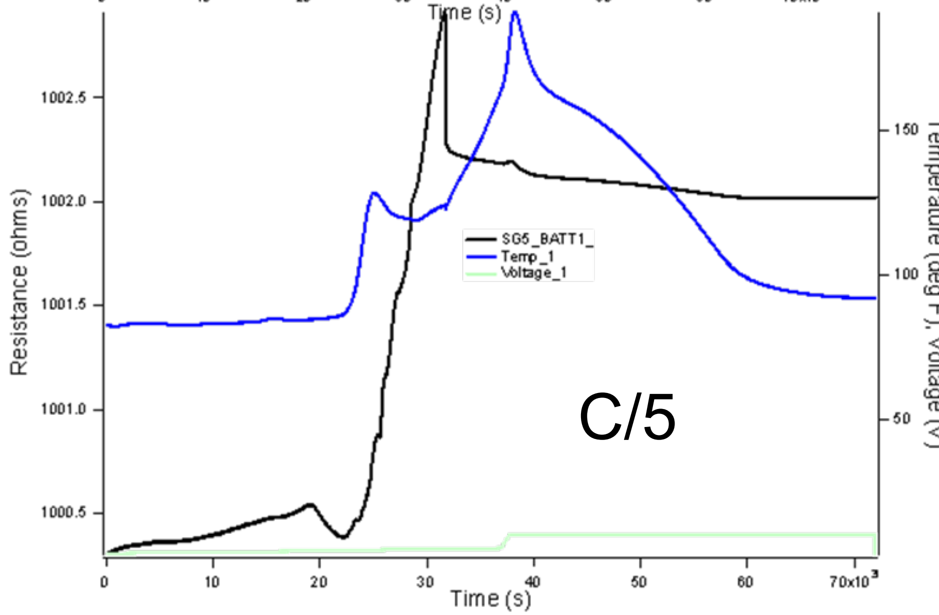


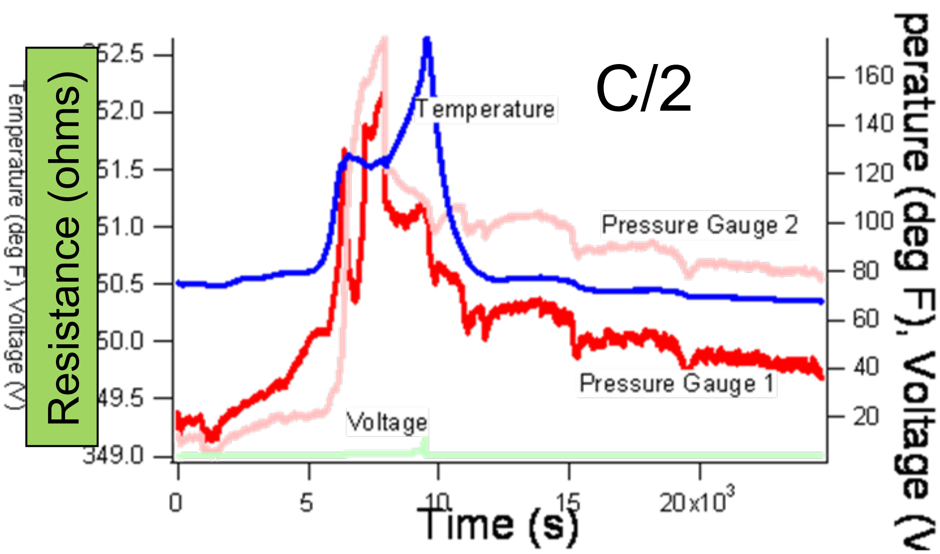


Overcharge of Polymer Pouch Lithium-ion Cell

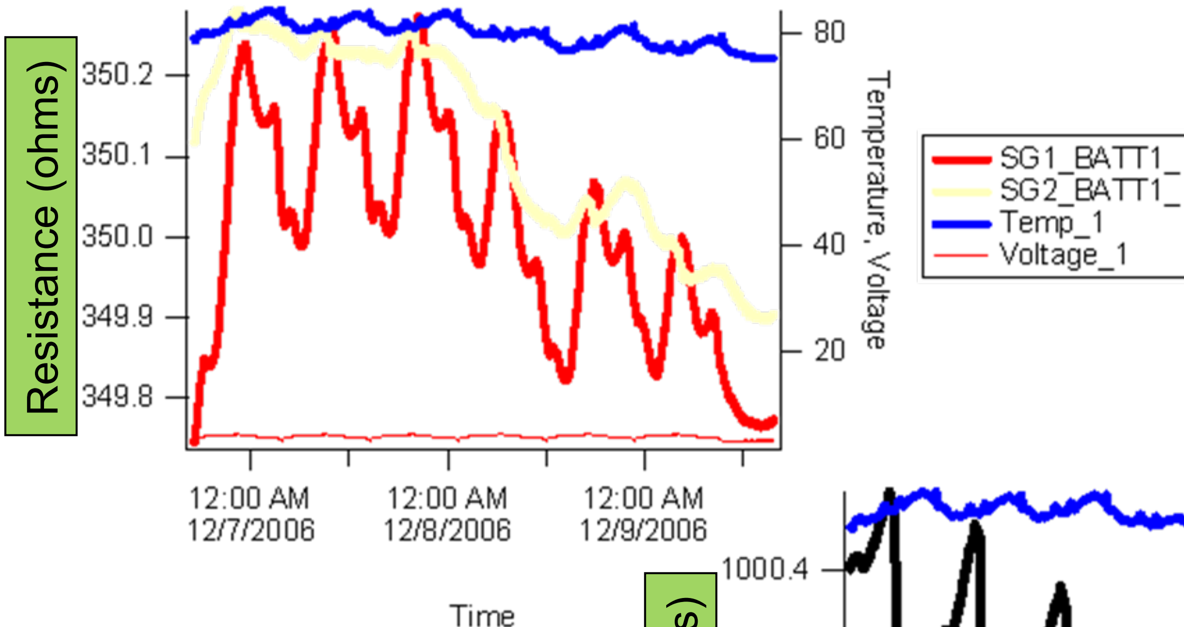


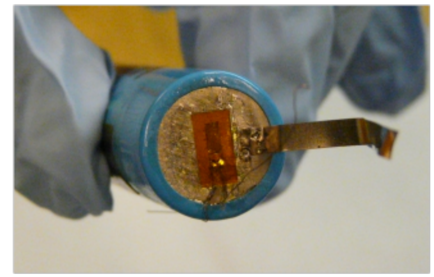




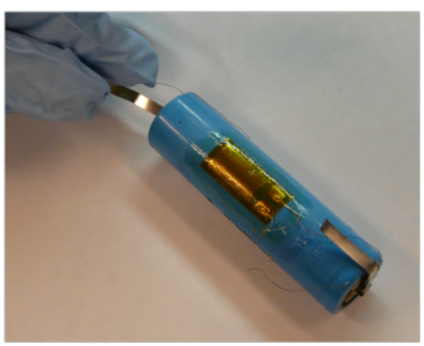


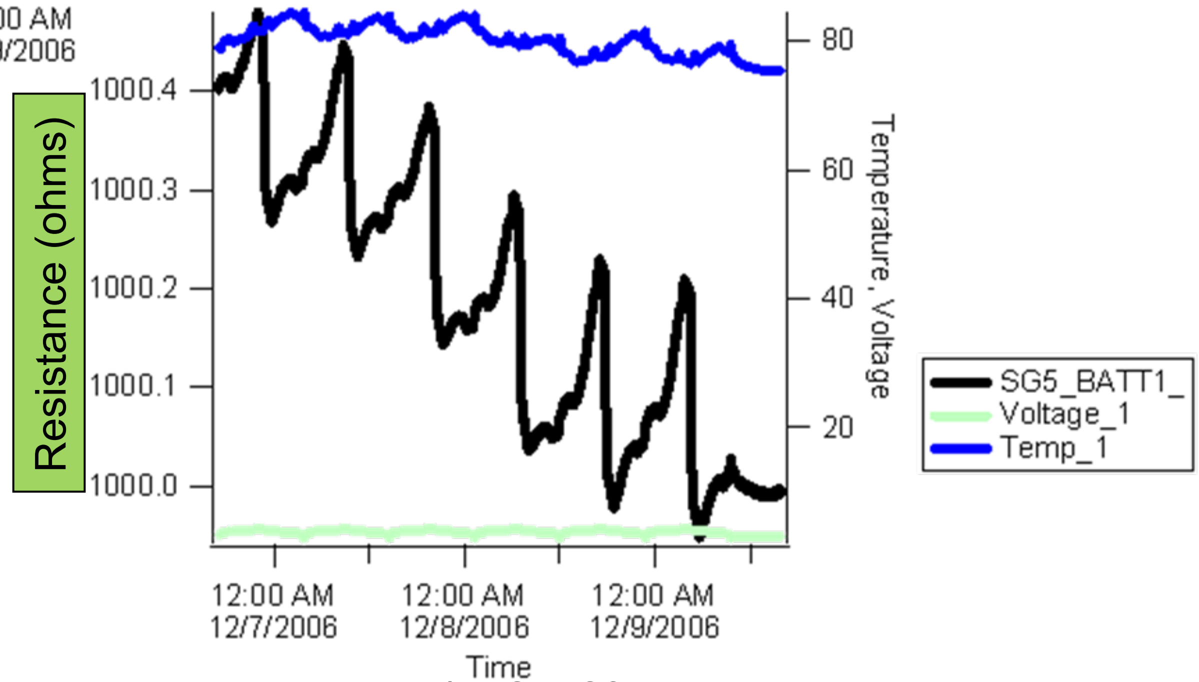
Cylindrical 18650 Li-ion Cell Design
Normal Charge/Discharge



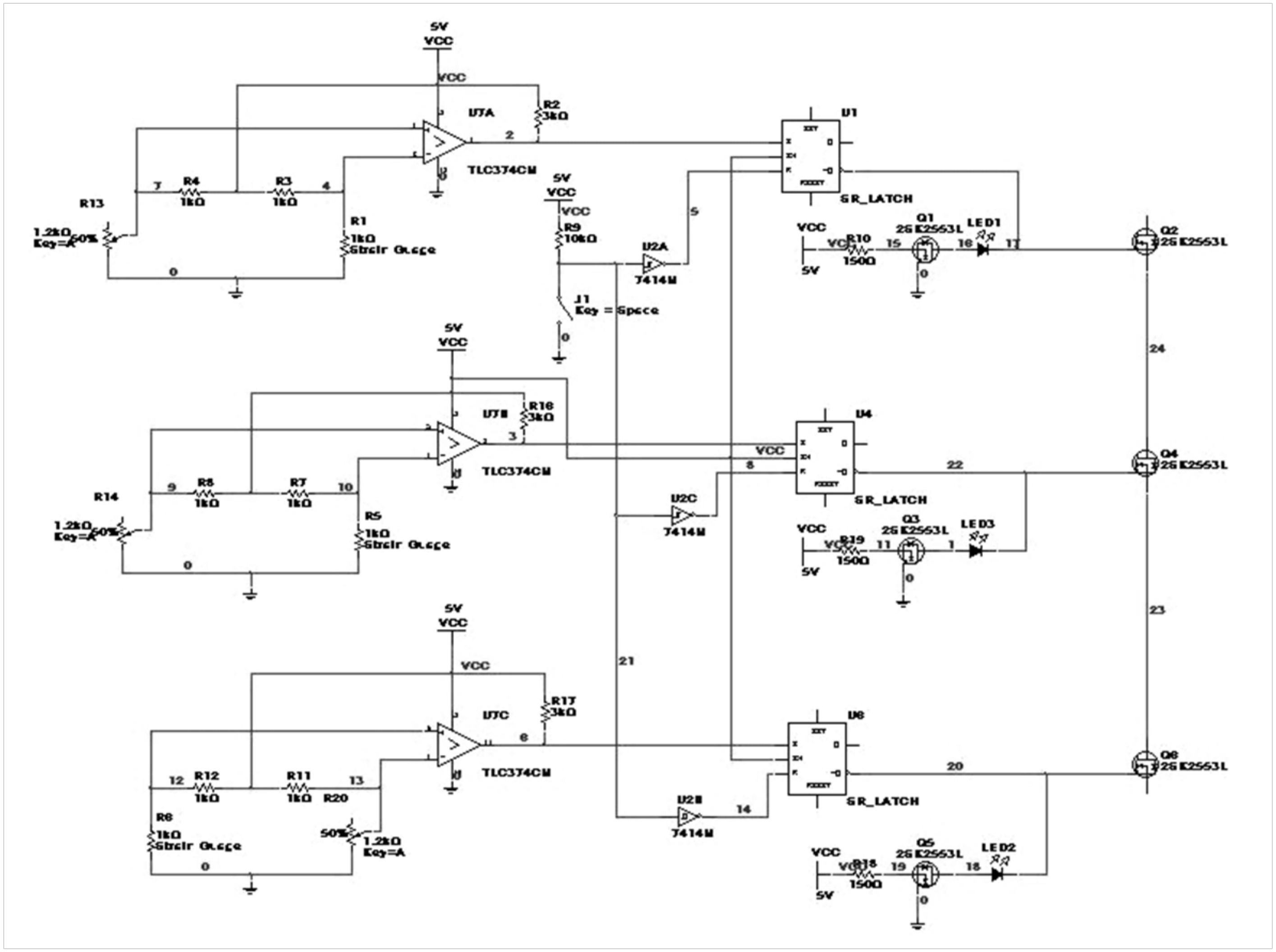


Changes are 0.1 to 0.2 ohms





Circuitry for Protection using Strain gauge signals (Summer Intern Design)



Summary and Conclusions

- The LG cells test data will be reported after completion of test program.
- The Tenergy cells performed very well under the protocols tested. Low capacity losses were observed for the protocols studied. Higher capacity losses at C/10 than the higher rates.
- The Tenergy cells showed a reasonable tolerance to abuse conditions except for the overcharge at medium rates (1 C and 0.5 C).
- Li-ion 5.5 Ah pouch cell test data at this time indicates that the restraint pressures are more important for the low temperature performance of the pouches (could be heating effects due to high internal resistance causing cell swelling that is minimized by the restraints)
- Microstrain gages can be used in critical applications where bulky thermocouples would hinder the number of sensors to be used.
- Li-S cells have made a lot of progress in the past few years and is a chemistry that is worth pursuing for our space applications that require short cycle life but very high energy density.

Acknowledgment

NASA-JSC ESTA (Energy Systems Test Area) for carrying out the LG cell tests, the Tenergy Performance Tests, the strain gage tests, Li-S cell tests

PCTest for carrying out the Tenergy Safety Tests

API for carrying out the Li-ion polymer pouch cell tests.

MPS for carrying out the performance and safety of the high energy Li-ion D cell test.